Available online at www.sciencedirect.com
ScienceDirect
Energy Procedia 66 (2015) 125 – 128
Energy Procedia

The 12th International Conference on Combustion & Energy Utilisation – 12ICCEU

Study on the burning of grain-molded propellant

Yue-Juan Yao, Bo Liu*, Qiong-Lin Wang, Shao-Wu Liu, Lun Wei, Yuan-Bo Zhang
Xi'an Modern Chemistry Research Institute, Xi'an 710065, PR China

Abstract

The investigation of the burning of grain-molded propellant comprises progressive burning, ignition and internal ballistic property. The grain-molded propellant is extruded by high energy nitramine propellant in the professional mould. The grain-molded propellant was studied by closed-bomb test, ignition simulation equipment test and 30mm simulation gun test. The characteristics of p-t and L-B curves were analyzed for different density of grain-molded propellant. The influence law of density on the burning property of the grain-molded propellant was obtained. The results show that the bigger the density of the grain-molded propellant is, the better its progressivity is. And the progressivity of sample3 is the best, whose density is 1.25 g•cm^{-3}. The muzzle velocity of sample3 increases 5.3% than that of high energy nitramine propellant.

Peer-review under responsibility of the Engineering Department, Lancaster University

Keywords: high energy nitramine propellant; grain-molded propellant; progressive burning; ignition; internal ballistic property

1. Instruction

Far gunshot and great power is the object of development of gun. It is one of the effective ways to improve the power of artillery that the charging energy and the energy utilization rate is increased[1-3]. Grain-molded propellant is a new gun propellant charge of high loading density. It is molded by high energy nitramine propellant grain in a professional mould. It can utilize effectively the chamber space to achieve high loading density. The energy density in unit volume of grain-molded propellant can be enhanced by 20%～40%[4]. The high loading density and excellent progressive burning is obvious advantage of grain-molded propellant. The high energy density grain-molded propellant charge has great influence on the ballistic performance of artillery. It can promote the tactical guideline of gun such as muzzle velocity, gunshot, power[5-6].

Grain-molded propellants start burning and disintegrating after they are ignited. Part of propellant combustion heat will be translated into artillery kinetic energy to increase the muzzle velocity. Three kinds of density of grain-molded propellant were produced in this paper. Their progressive burning was studied with closed-bomb, ignition simulation equipment and 30mm simulation gun test.

2 Experiments

2.1 Propellant Samples

Peer-review under responsibility of the Engineering Department, Lancaster University
doi:10.1016/j.egypro.2015.02.071

The three samples, which labeled as from sample1 to sample3, were home-made. They were produced from the high energy nitramine propellant coated with the energetic binder in the professional mould. The density of the samples is 1.05 g • cm^{-3}, 1.15 g • cm^{-3}, 1.25 g • cm^{-3} in turn.

2.2 Interrupted-burning simulation equipment test

The interrupted-burning phenomena of three samples were studied by interrupted-burning simulation equipment. The ignition mode is electric primer and powder. The ignition pressure calculated is 5MPa.

2.3 Closed-bomb test

The more progressive the burning of three samples and the base propellant were studied by the closed-bomb test .

Pr was defined as: $Pr = Bs \times Ls / (L_{0.1} + L_{0.3})$ (1)

where *Pr* was the progressivity index; *L* was the vivacity in closed-bomb test; *B* was the relative pressure in closed-bomb test; *Bs* was the *B* value corresponding to grain splitting; *Ls* was the *L* value corresponding to grain splitting; $L_{0.1}$ was the *L* value corresponding to *B*=0.1; $L_{0.3}$ was the *L* value corresponding to *B*=0.3. *Pr* reflected the progressivity of a real gun propellant.

2.4 30mm simulation gun test

Three samples and base grain propellant to be tested were filled into the chamber of 30mm simulation gun at 20℃. The barrel maximum pressure (*Pm*) was recorded by a copper cylinder, and the muzzle velocity (V_0) was calculated using the distance between two electromagnetic targets divided by the time interval of the bullet passing through.

3 Results and Discussion

3.1 Interrupted-burning setup test

The interrupted-burning phenomena of molded-grain propellants were studied by interrupted-burning simulation equipment. Figure1 shows the experimental result of the sample1 before and after the test, Figure2 shows the experimental result of the sample2, Figure3 shows the experimental result of the sample3. Table1 lists ignition delay time of 5MPa.

Figure1. The sample1 before and after the interrupted-burning simulation equipment test

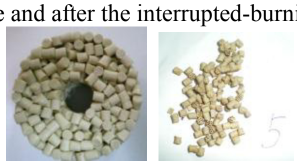


Figure2. The sample2 before and after the interrupted-burning simulation equipment test

Figure3. The sample3 before and after the interrupted-burning simulation equipment test

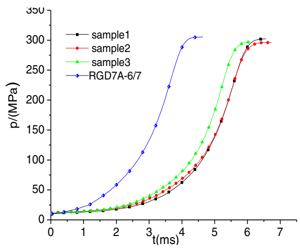
Table1. the results of interrupted-burning simulation equipment test

sample	density, （$g\cdot cm^{-3}$）	t_{5MPa} ms	The results of test
sample 1	1.05	3.5	Photo3
sample 2	1.15	4.7	Photo5
sample3	1.25	6.3	Photo7

Ignition delay time of three samples is relatively short and ignition delay time of sample1 is the shortest. That indicates the actual ignition condition can ignite the molded-grain propellant. The rule is obtained that the higher the density of the molded-grain propellant is, the longer its ignition delay time is. The molded-grain propellant starts disaggregating when it is impacted produced by the ignition action. Then burning surface increases quickly after the base propellants break from the module and begin to burn. The ignition delay time is decreased. The disaggregation of the molded-grain propellant with low density is easier than that of the high. Ignition delay time of three samples becomes long gradually in the order of sample1, sample2, sample3.

3.2 Closed-bomb test

The burning properties of the three samples and the RGD7A propellant were tested by closed-bomb test. Figure4 shows the *p-t* curves. Figure5 shows the *L-B* curves. Table2 lists the result for the effect of density upon the grain-molded propellant by *Pr.* The values of *Pr* is calculated with Eq. (2).



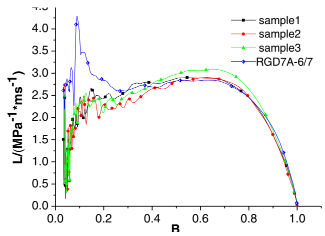


Figure4. *p-t* curves of three samples and RGD7A **Figure5.** *L-B* curves of three samples and RGD7A

Table2. the samples values of *Pr* by calculation

sample	$\rho/(g\cdot cm^{-3})$	$L_{0.1}$	$L_{0.3}$	Ls	Bs	Pr
RGD7A-6/7		3.8688	2.6120	2.8449	0.6139	0.269
sample1	1.05	2.449	2.604	2.901	0.626	0.359
sample 2	1.15	2.133	2.402	2.892	0.600	0.382
sample 3	1.25	2.304	2.521	3.091	0.646	0.414

The result of Fig.4 shows that the chamber pressure rise rate of grain-molded propellants become slower with increasing of their density. The rising rate of initial chamber pressure becomes slowly with their density increasing. The experimental results show that the bigger the density of grain-molded propellant is, the slower the rising rate of initial pressure increases in some density range. Grain-molded propellant can curb effectively the rising rate of initial chamber pressure during propellant combustion process. The similar ruler is indicated by the experimental result of density effect on the grain-molded propellant in Figure5. Table2 shows that the values of grain-molded propellant *Pr* is higher than that of RGD7A propellant, which indicates that the grain-molded propellant has an excellent progressive burning property.

The energetic binder starts burning firstly when grain-molded propellant is ignited. The burning of binder accelerates disaggregation combustion of grain-molded propellant. The burning surface is small in the early combustion stage. So the rising rate of the initial chamber pressure is reduced effectively when grain-molded propellant begins burning. The combustion of grain-molded propellant starts with the minority hotspots or the disfigurement of the coated layer. The burning rate and burning surface increases gradually as the hotspots and the disfigurement congregate during combustion process. The maximum chamber pressure will appear instantly at the largest chamber space. Grain-molded propellant can control the rising of initial chamber pressure. It is achieved that the compacter the grain-molded propellant is, the slower it disaggregate and the better its progressive burning is.

3.3 30mm simulation gun shooting

Table3 shows the results of the samples in 30mm simulation ballistic gun shooting. The experimental results show that the muzzle velocity and loading weight of three samples increases compared with that of base propellant under the equivalent pressure of maximum chamber. The muzzle velocity increase of sample3 is 5.7%, which is the best in three samples.

Table3. the results of samples obtained by interior ballistic test

sample	m, g	p, MPa	v_0,($m \cdot s^{-1}$)	Δv, %
RGD7A-6/7	180	443.0	1354.7	
sample1	212.4	432.4	1392.6	2.8
sample 2	233.5	435.7	1408.9	4.0
sample 3	260.2	433.3	1431.5	5.7

Notes：*m* is the weight of charge, *p* is pressure, v_0 is muzzle velocity, *Δv* is muzzle velocity increase.

The propellant combustion in gun chamber should be divided into three stages, such as the early, the middle and the late. In the early, the gas generation rate must be reduced in order to inhibit the abrupt pressure rise. High temperature and high pressure gas produced by propellant combustion can promote the projectile motion. The projectile accelerates in the middle. In order to protect the normal acceleration pressure in projectile, the burning rate of propellant must gradually speed up in the late.

The molded-grain propellant is molded together by base propellant grain in the special mould. The module charge can hold the gas generation rate to prevent the rapid rising of chamber pressure in the early of combustion. With the disaggregation of molded-propellant, the gas generation rate increases more quickly in the middle of combustion. The promotion of the gas generation rate counteracts the enlargement of the chamber space produced by projectile motion. Sufficient power is provided for the movement of the projectile motion in the barrel. The muzzle velocity of three samples increases 2.8%, 4.0%, 5.7% respectively. The results of the interior ballistic tests indicate the general trend is that the muzzle velocity and the loading weight improve from sample1 to sample3.

4 Conclusions

(1) The disaggregation combustion of grain-molded propellant can restrain the gas generation rate to prevent the rapid rising of chamber pressure in the early of the combustion. But it can improve gas generation activity in the late of the combustion. This is conducive to increase the progressive burning of grain-molded propellant. The progressive burning of grain-molded propellant can improve as its density increases. The progressive burning property of grain-molded propellant is more and more excellent from the density of 1.05 $g \cdot cm^{-3}$ to the density of 1.25 $g \cdot cm^{-3.}$

(2) The density of grain-molded propellant has great effect on the ballistic property of weapon. Under the equivalent pressure of maximum chamber, the muzzle velocity of the sample3 with the biggest density increases by 76.8 $m \cdot s^{-1}$. The muzzle velocity increase is 5.7%.

References

[1]Rivera J. *ADA* 242661.

[2] Z.S WANG, *Chinese Journal of North University of China*.2001.36.

[3] Johan Dahlberg, etal. *27rd ICT*, 2006.

[4] Y.J.YAO, S.W.LIU, Q.L.WANG, *Chinese Journal of Energetic Materials*, 2012, 35, 51-54.

[5] Y.J.YAO, S.W.LIU, Q.L.WANG, *Chinese Journal of Energetic Materials*, 2013, 36, 58-60.

Corresponding author. Tel.: +86 29 88294038 *E-mail adress: liubliw@163.com*